ANOTHER VIEW FROM TIROS I OF A SEVERE WEATHER SITUATION MAY 16, 1960 [1]

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ABSTRACT

On May 16, 1960, TIROS I televised a series of pictures over the central United States during a severe local storm situation. Comparisons are made between the location of the isolated, bright cloud elements seen in those pictures and (1) the location of surface weather and synoptic features, (2) the location of sferics observations, and (3) the location of the upper-level jet maxima believed important in the development of severe local storm activity. Comparison is made of the cloud cover shown in the pictures to the cover indicated by the surface observations. Apparent brightness and cloud cover of the pictures is discussed in relation to both the weather activity occurring at the surface, and cloud types and cover observed at the surface. Also, cloud streets which appear in the photographs are discussed relative to the observed wind patterns and vertical temperature structure.

Evidence is presented indicating that the severe local storm activity occurred beneath three bright mesoscale cloud masses—the more vigorous activity occurring beneath two masses which were largely isolated from the large-scale patterns. Further, the latter two clouds masses are shown to be correlated well in location with sferics observations and jet stream maxima in the lower levels of the atmosphere

1. INTRODUCTION

Large-scale, bright cloud areas have frequently appeared in the many pictures received from the TIROS meteorological satellites. A limited number of these pictures have shown small-scale very bright cloud patches somewhat isolated from the large-scale patterns. These patches, because of their relative isolation, strong reflectivity, and mesoscale proportions, have suggested intense convective activity, such as a system of well developed thunderstorms perhaps capable of producing a family of severe local storms. In at least one instance to date, such a case has been documented [11].

On May 16, 1960, during pass 659, TIROS I televised a sequence of pictures showing bright, isolated masses of clouds over the central United States during a severe weather situation. A study of that case was undertaken to provide evidence supporting the hypothesis that these distinctive cloud masses were associated with the occurrence of severe weather in the Middle West. In particular, these clouds were investigated relative to synoptic observations, analyses, and sferics. In addition, the photographs were compared with surface cloud observations to aid in identifying the clouds in the pictures. Also, rather prominent wave clouds or cloud streets appearing in the satellite pictures were examined relative to the theoretical models of cloud streets.

[1] This research has been supported by the National Aeronautics and Space Administration.

2. DISCUSSION OF PICTURES

Five wide-angle TIROS I pictures were photographed at approximately 30-second intervals between 205433 GMT and 205831 GMT on May 16, 1960 over the central United States. To facilitate discussion of the pictures, State borders have been superimposed on each of the five pictures (figs. 1–5). Rectification and gridding was done using the procedures discussed in [10].

Two of the three cloud features of interest (A, B, and C) are shown in the figures 2–4. Note that the three major bright areas were located (A) in northern Missouri and southeastern Iowa, (B) over the Illinois and Missouri border, and (C) over Indiana. The cloud mass C, since it is not isolated as are the clouds A and B, does not stand out as clearly. While the western border is well defined, very bright, and easily distinguished, the eastern border blends into the large-scale cover.

The cloud masses described above appeared considerably brighter on the transparencies than in reproduction here. Unfortunately, prints of satellite pictures do not usually differentiate scales of brightness as adequately as do the original 35-mm. transparencies.

Several other prominent and interesting cloud patterns appearing in the pictures are worthy of mention here. For instance, over central Oklahoma and northern Texas (figs. 1 and 2) the clouds are organized in parallel lines or streets. The lines are rather closely spaced and appear comprised of small cloud elements much like cumulus

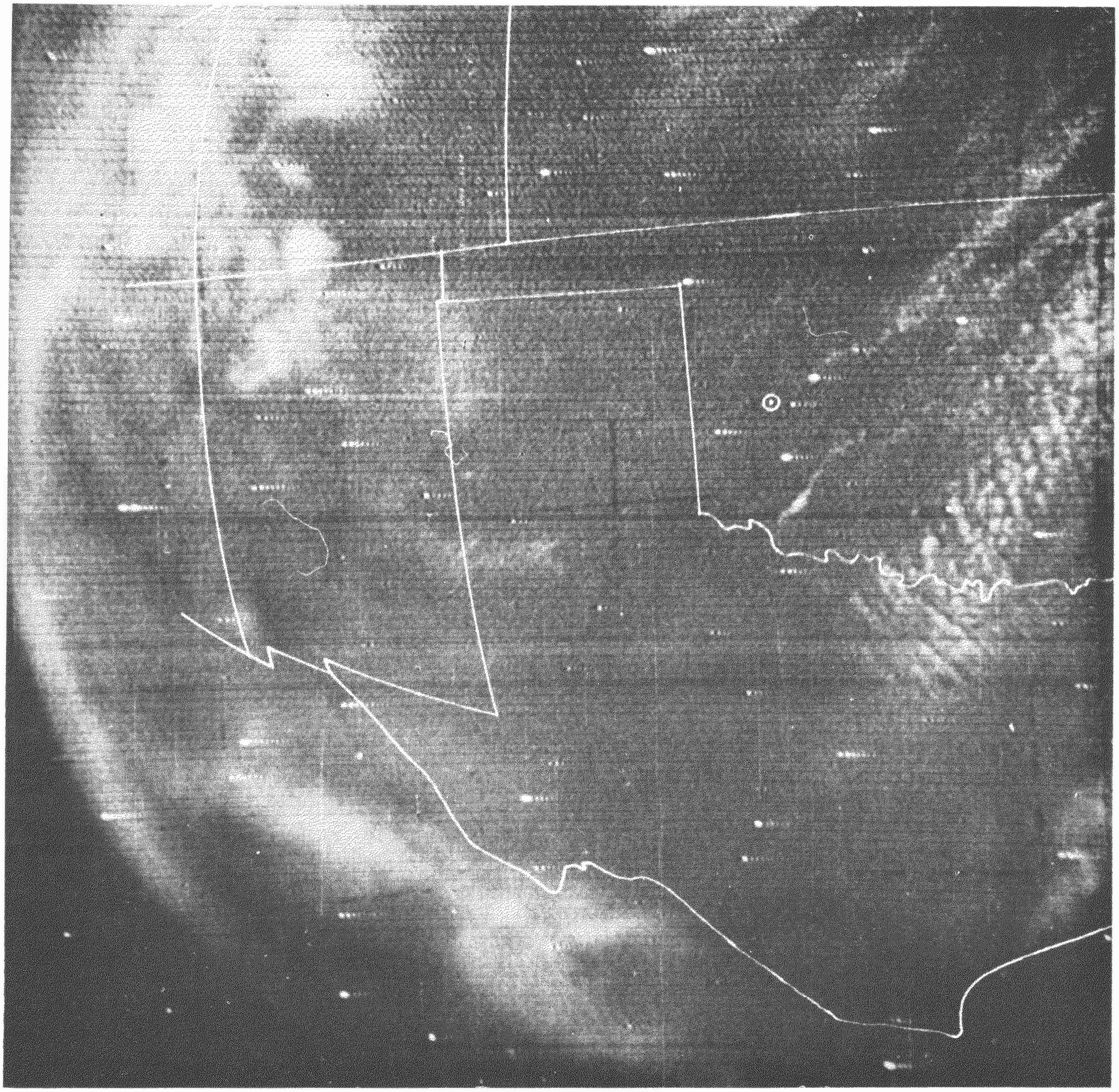

FIGURE 1.—Gridded photograph of frame 4 from the TIROS I pass 659, May 16, 1960, 2100 GMT. Cloud streets are seen at the right in the picture.

cells. Farther to the east, a long, moderately bright cloud band may be seen oriented northeast-southwest through central Arkansas (fig. 2). This band suggests a line of cumuliform clouds.

In figure 3 the moderately bright, extensive cloud cover across the top of the picture was located in the western Lakes area westward into Minnesota and northwestern Iowa. Immediately to the east, over the eastern Great Lakes area (fig. 5), the clouds became filmy and streaked, suggesting that they were cirriform.

Figure 6 is a schematic of the essential features in the five TIROS I photographs. The cloud features are described by the prominence of the boundaries and relative brightness. This presentation, hopefully, will permit the reader to view the features in composite.

3. COMPARISONS OF PICTURES AND METEOROLOGICAL ANALYSES

SURFACE ANALYSIS

The surface chart prepared from the 2100 GMT surface airways observations corresponds to the picture times.

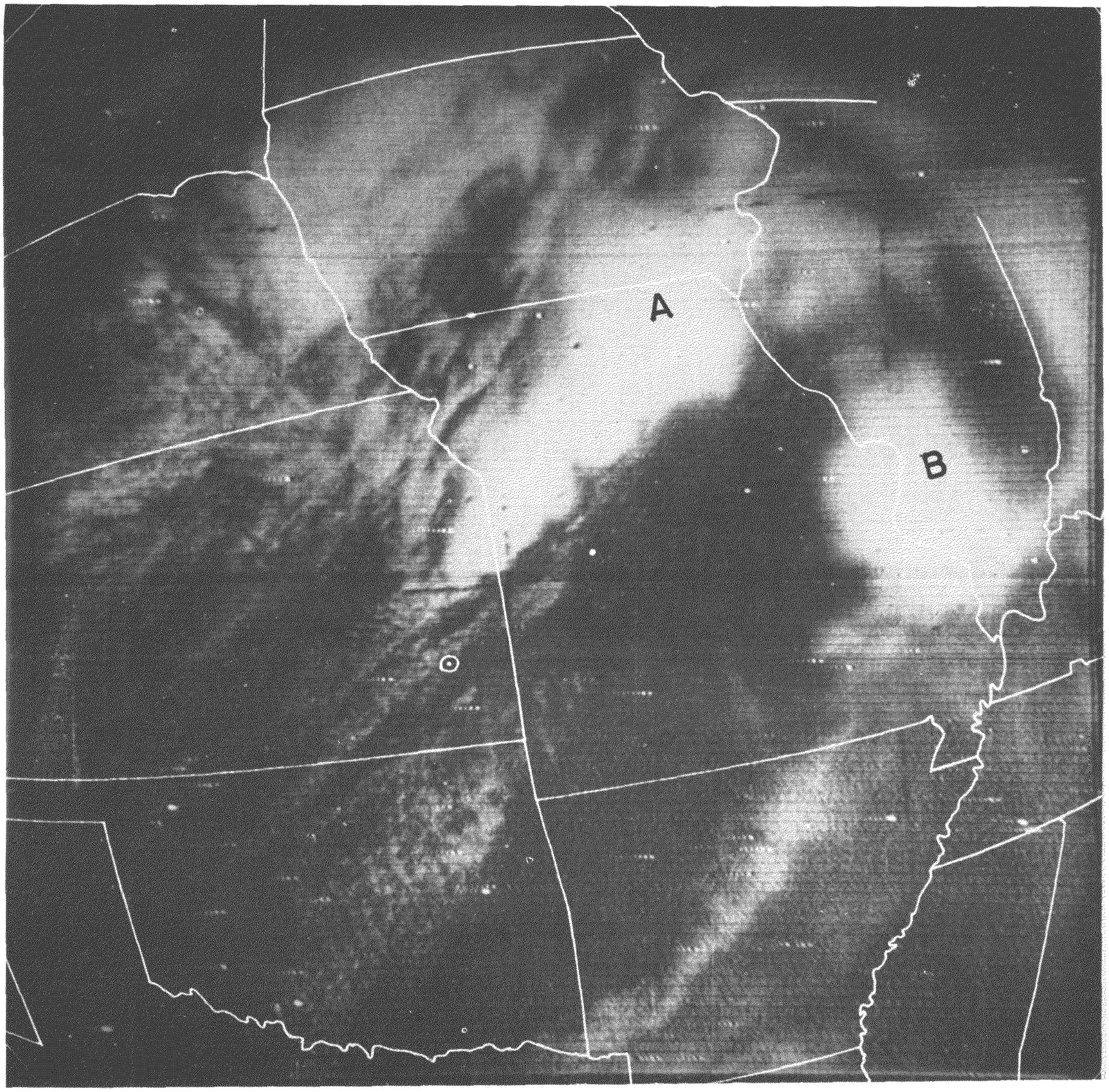

Figure 2.—Gridded photograph of frame 7 from the TIROS I pass 659, May 16, 1960, 2100 GMT. Two of three very bright cloud masses associated with severe weather are designated A and B.

A series of hourly charts was prepared to observe short-period changes and to check the continuity of the 2100 GMT analysis. In order that these analyses might be as objective as possible, they were performed independently of the picture rectifications (geographical location of the cloud elements).

In the interest of brevity, only the 2100 GMT surface analysis is shown here (fig. 7). Two small waves appeared on the cold front—one in eastern Kansas and another in western Oklahoma. A warm front extended from the Iowa low pressure center southeastward into West Virginia. Continuous light rain fell to the north of the Iowa low pressure center. A few rain showers were reported in Michigan north of the warm front.

Of primary interest were the thunderstorms and associated severe weather reported in the warm sector. One group of thunderstorms produced some hail along the cold front in northern Missouri; a second group was accompanied by tornadoes and strong winds near the Illinois-Missouri border; and a third group spawned a

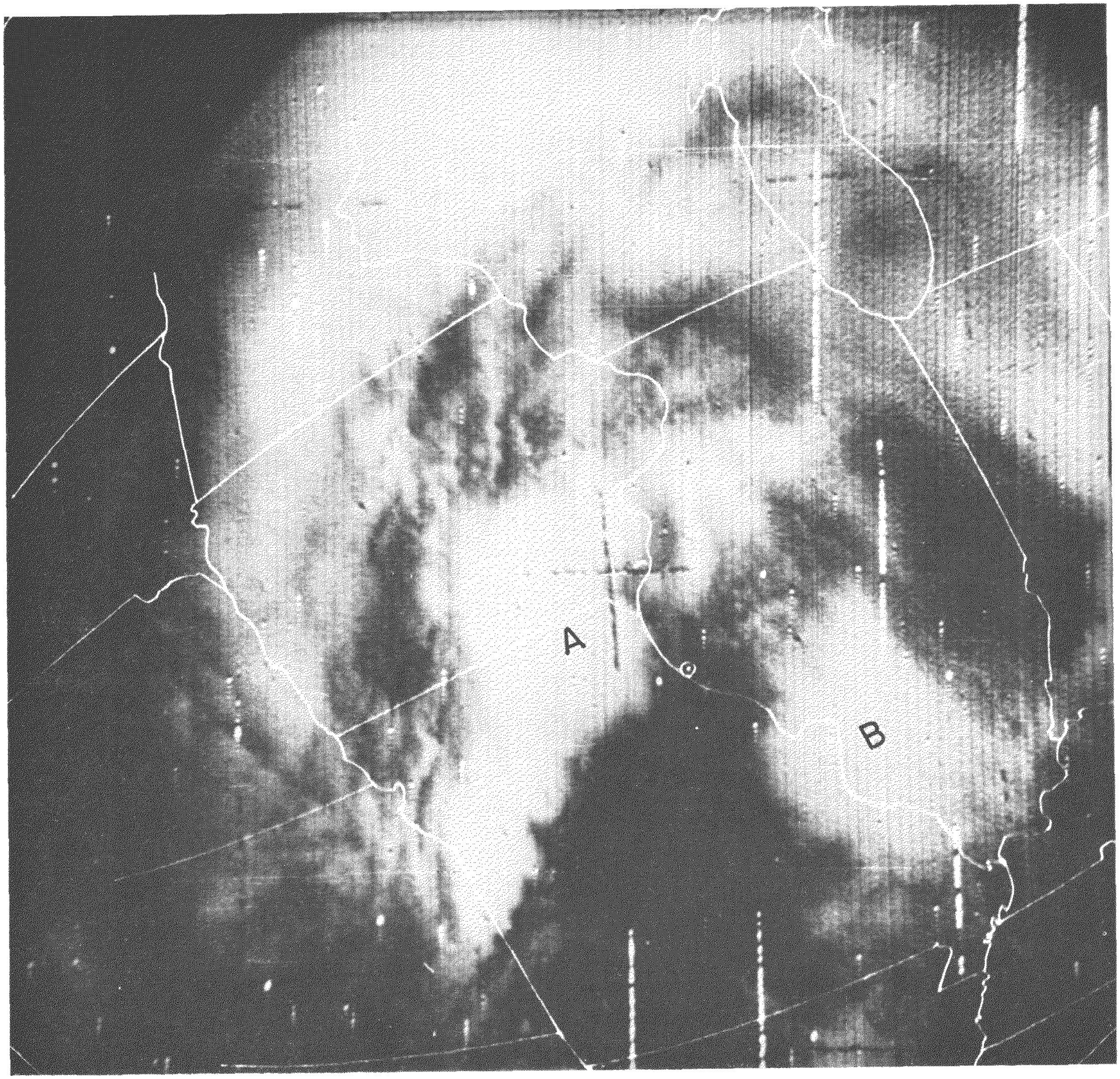

FIGURE 3.—Gridded photograph of frame 11 from the TIROS I pass 659, May 16, 1960, 2100 GMT. The cloud masses A and B are the same two which appear in figure 2. These two masses are somewhat isolated from the large-scale cover to the north.

lone tornado in Indiana. The convective systems are designated A, B, and C, respectively, in figure 7.

Severe weather occurred over a span of 5 hours between 1830 and 2330 GMT (fig. 8) but a good portion of the activity was observed within one hour of 2100 GMT—the time of the TIROS pictures. Though the severe weather during this period was outside the Severe Local Storms Research Network, four mesoscale pressure systems could be detected (fig. 7)—two mesohighs and two mesolows. These systems were analyzed from the airways observations through close examination of the behavior of the wind, pressure, temperature, and weather in time. The analysis of these pressure systems is crude in comparison with that which might be prepared from a dense network of accelerated microbarograph and thermograph traces [5].[2] For the scope of this report there appears to be sufficient evidence that pressure disturbances of the type indicated did exist in the areas shown. In short, the

[2] Dr. Tetsuya Fujita of the University of Chicago has been performing a very detailed mesoanalysis of this situation.

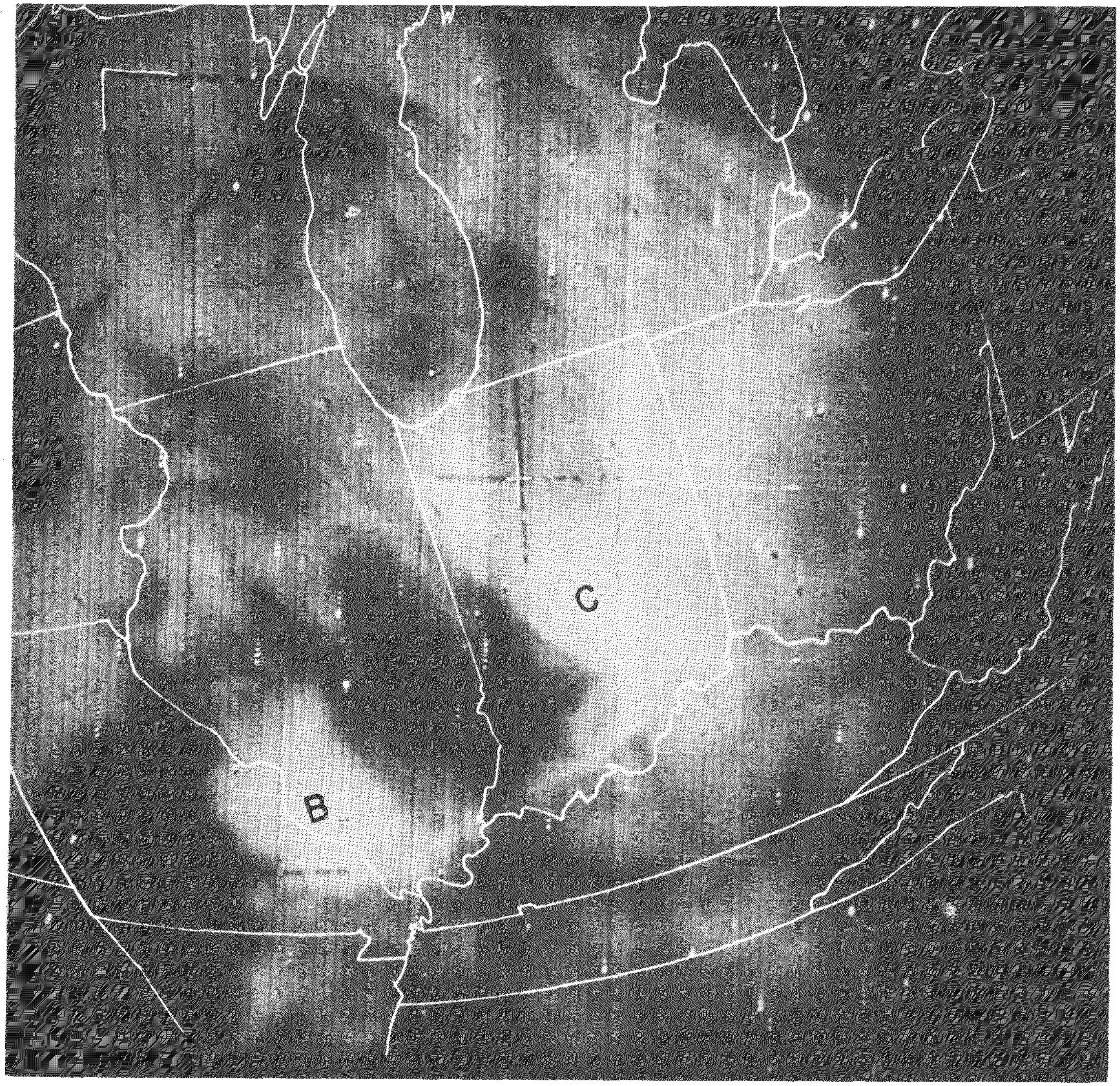

FIGURE 4.—Gridded photograph of frame 15 from the TIROS I pass 659, May 16, 1960, 2100 GMT. The third bright cloud mass appear here as area C. This cloud mass is not isolated from the large-scale cloud cover as are clouds A and B.

severe weather activity in eastern Missouri and that in Indiana were each associated with a mesohigh and the accompanying pressure rise or pressure jump line. It appears that the storms in northern Missouri were associated with the cold front, although one should not rule out the possibility of a mesosystem there. The location of the cold front in Missouri was somewhat nebulous because of the convective activity present.

The convective system C, over Indiana, was less severe at 2100 GMT than were the two disturbances to the west. The only tornado associated with it developed 45 minutes earlier. Its history dated back several hours, having earlier passed through central Illinois and northern Missouri. In all likelihood the system was in a state of decay.

There was no definite indication of unusual weather activity within the two mesolows. Possibly, though, the mesolow in northern Indiana was a tornado-Low or the remnants of the tornado observed in Indiana (figs. 7 and 8).

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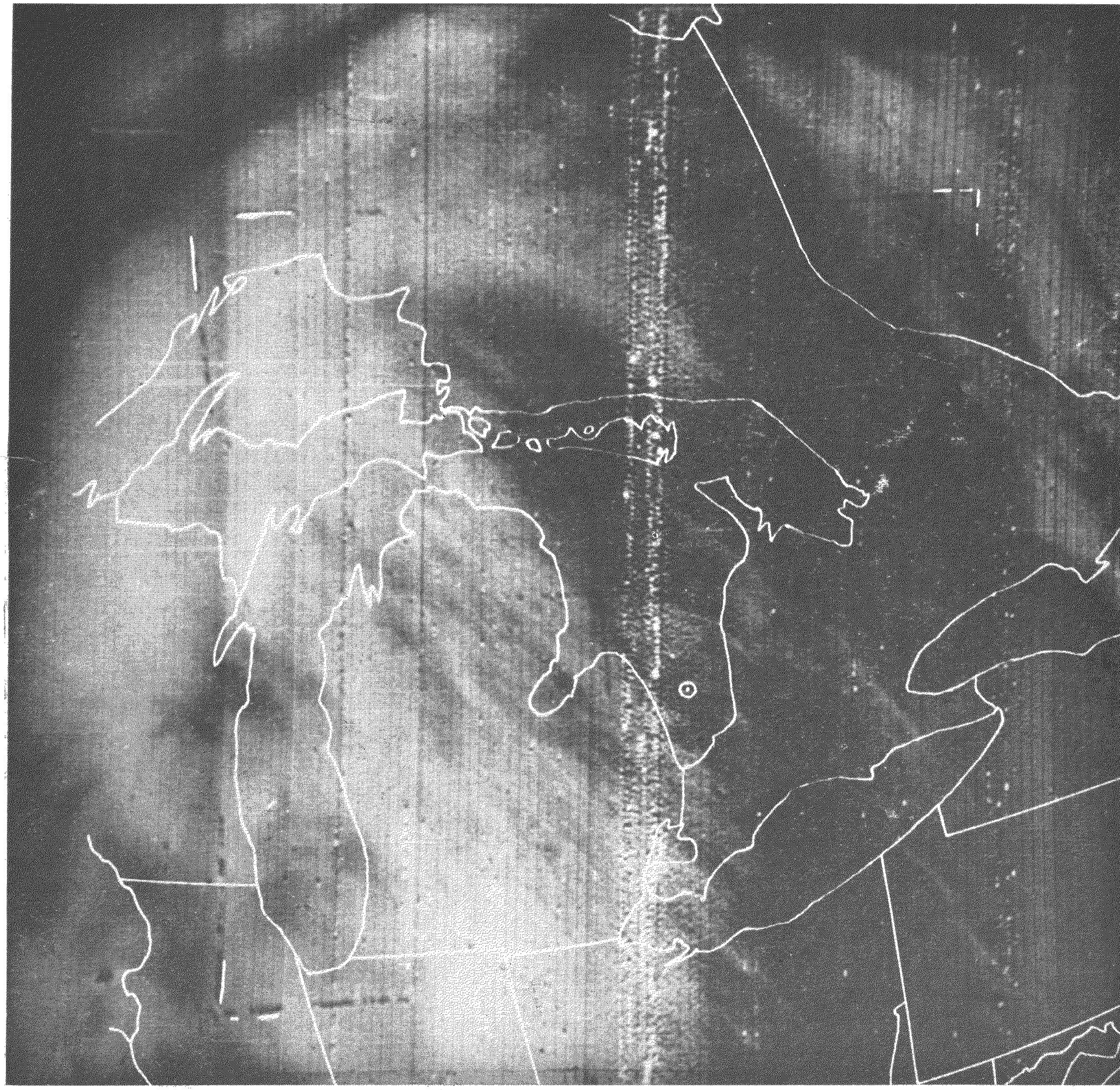

FIGURE 5.—Gridded photograph of frame 19 from the TIROS I pass 659, May 16, 1960, 2100 GMT. A portion of the large-scale cloud cover appears at the left. The filmy and streaked clouds through the center of the picture are associated with cirrus reported in the Great Lakes area.

The severe weather reports within 1 hour of 2100 GMT, and the major surface synoptic features and the surface weather from the 2100 GMT surface chart are shown in composite with the rectified cloud schematic in figure 9 to expedite comparisons. One notes immediately the excellent correlation between the location of the thunderstorm and the severe storm reports relative to two of the three bright cloud masses—one in northern Missouri and southeastern Iowa (area A), and the other in eastern Missouri and southwestern Illinois (area B). The cold front "slices" through the center of the first mass and a squall or pressure jump line through the second.

Geographical agreement between the mesosystem and the third bright cloud mass, C, is not as striking as for the two systems to the west. Thunderstorms were reported both within and without the bright cloud while the squall line, as analyzed, is not aligned with the long dimension of the bright cloud. Lack of agreement may have been influenced by two factors. One, the eastern portion of cloud mass C was very diffuse with the bright-

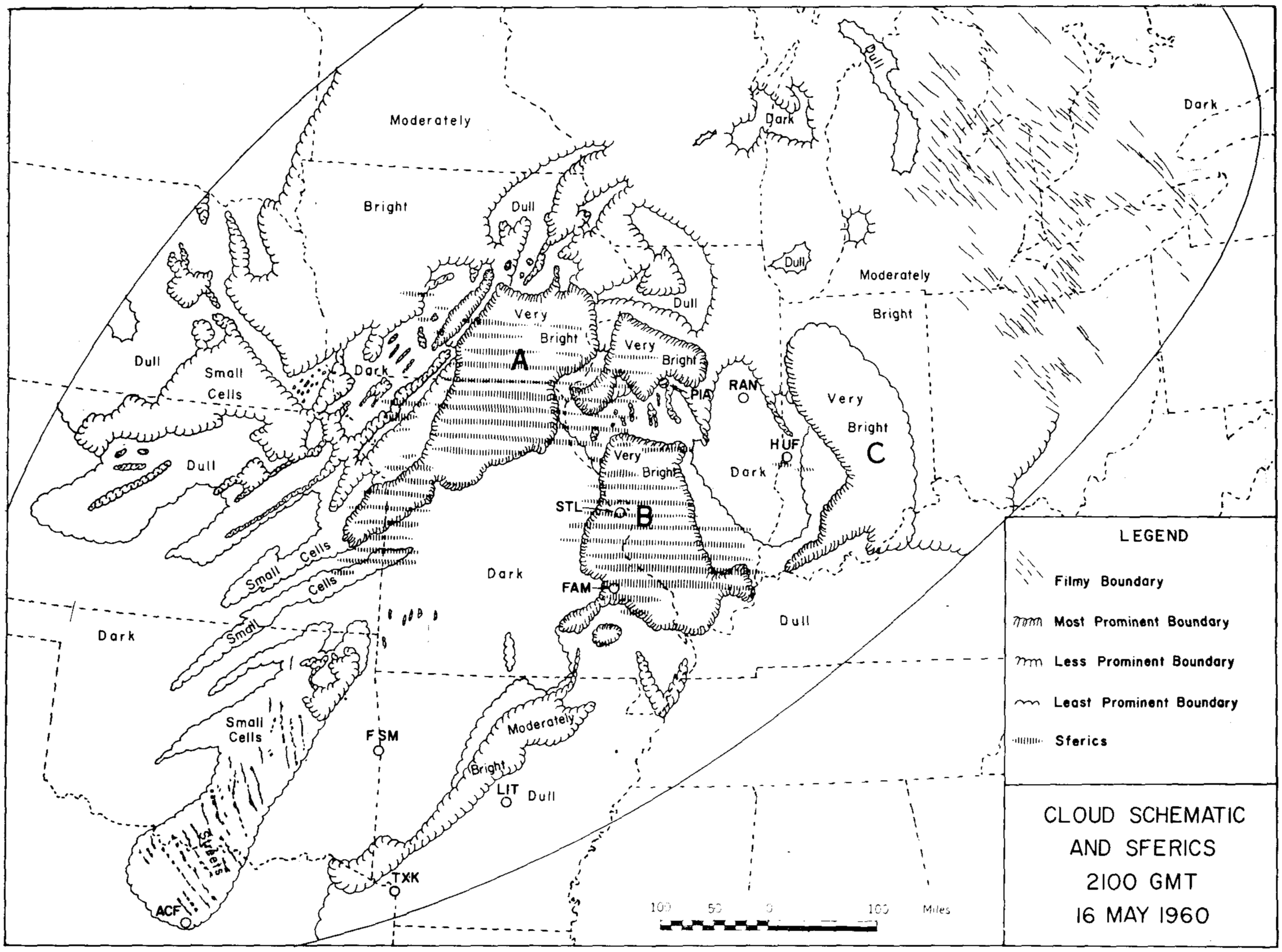

FIGURE 6.—Schematic rectification of the cloud features appearing in figures 1–5. Areas A, B, and C correspond both to those identically lettered cloud masses in figures 2–4 and the severe storm systems in figure 7. All brightness descriptions were determined subjectively from the pictures. Superimposed on the schematic are the 2100 GMT sferics locations taken from figure 10.

ness decreasing toward the east, eventually blending into the large-scale cloud cover (fig. 4) and thus precluding clear delineation of the eastern border. Two, since the disturbance in Indiana was old and decaying, it was not sharply defined.

SFERICS

Figure 10 represents the 50 kc. sferics observations from four station fixes during the interval 2055–2100 GMT, May 16, 1960. Quite obviously there was distinct and frequent sferics return from the area of northern and northwestern Missouri and southeastern Iowa and from the area of east-central Missouri and southwestern Illinois. Comparison of figures 7 and 10 shows these sferics reports correspond extremely well in location with two of the three areas of small-scale convective activity, areas A and B of figure 6, described earlier. In fact, these sferics reports probably outline, in greater detail than the surface observations, those areas where rather vigorous convective activity was taking place.

There was little or no 50 kc. sferics return of consequence at this time in Indiana, area C, even though observations of thunderstorms were made there. Several explanations may be given for this but a plausible one is that the Indiana storms, being less active and decaying, were emitting electrical disturbances in a different frequency range [4] than those to the west and southwest where the systems were vigorous and developing or regenerating, producing severe storms until 2330 GMT.

Since two convective areas (A and B) were shown to have been within the bounds of bright clouds seen from TIROS I, then the sferics observations and bright clouds should be expected to exhibit a measure of correlation. Figure 6, a composite of the sferics return and cloud schematic, reveals a correlation beyond expectation. The bright cloud areas match the greater portion of the sferics

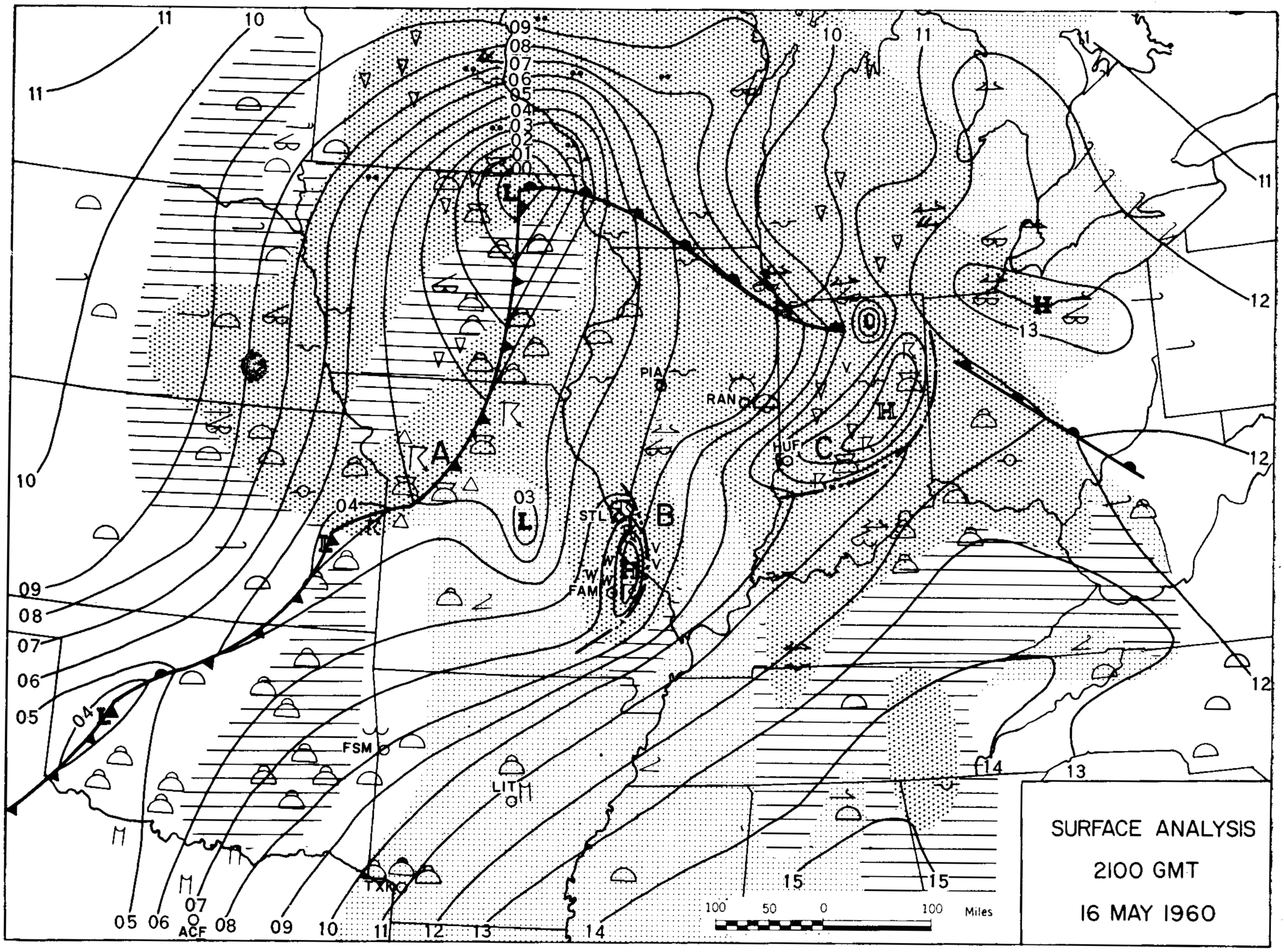

FIGURE 7.—Surface chart for 2100 GMT, May 16, 1960, showing, in addition to the pressure and frontal analysis, the observed cloud cover, observed cloud types, and observed weather. The cloud cover is separated into the four categories described in the text. Successive categories are lighter in shading. Category 1 (essentially overcast) is described by heaviest shading, while category 4 (clear or scattered) is unshaded. Cloud types, weather, fronts, etc., are represented by the usual symbols. The legend of figure 9 also applies.

return area to the extent that the boundaries are coincident at many points.

UPPER AIR STREAMLINE ANALYSES

Streamline analyses were performed (after the technique of Palmer et al. [9]) for the 5,000- and 20,000-ft. levels from the 1800 GMT May 16, 1960 and the 0000 GMT May 17, 1960 upper air observations over the central portion of the United States (figs. 11 and 12). The object of the analyses was to determine the configuration of low- and high-level jet streams and jet maxima for the purpose of locating a convective mechanism, as proposed by Beebe and Bates [1], which might be related to the bright clouds appearing in the TIROS I pictures from pass 659.

In short, the Beebe and Bates divergence models for location of the convective mechanism were evolved from a determination of the divergence fields about jet maxima at both low and high levels. The divergence field may be determined from the divergence term of the vorticity equation by evaluating from the wind field alone the advection of relative vorticity about a jet maximum. If the configuration of a high-level jet maximum over a low-level jet maximum is such that divergence is occurring over convergence, Beebe and Bates propose that the vertical motion and modification of the temperature distribution would release convective instability.

The analyses shown in figures 11 and 12 cannot be considered unique because of the sparseness of upper-air observations. A quantitative evaluation of the divergence term from these analyses would then be somewhat presumptuous for the scale we are considering here. Therefore, the models were applied on the 5,000- and 20,000-ft. charts to locate the convective mechanisms at the times considered. The models are the cases of (1) a jet stream of no curvature (fig. 11a), (2) a cyclonically

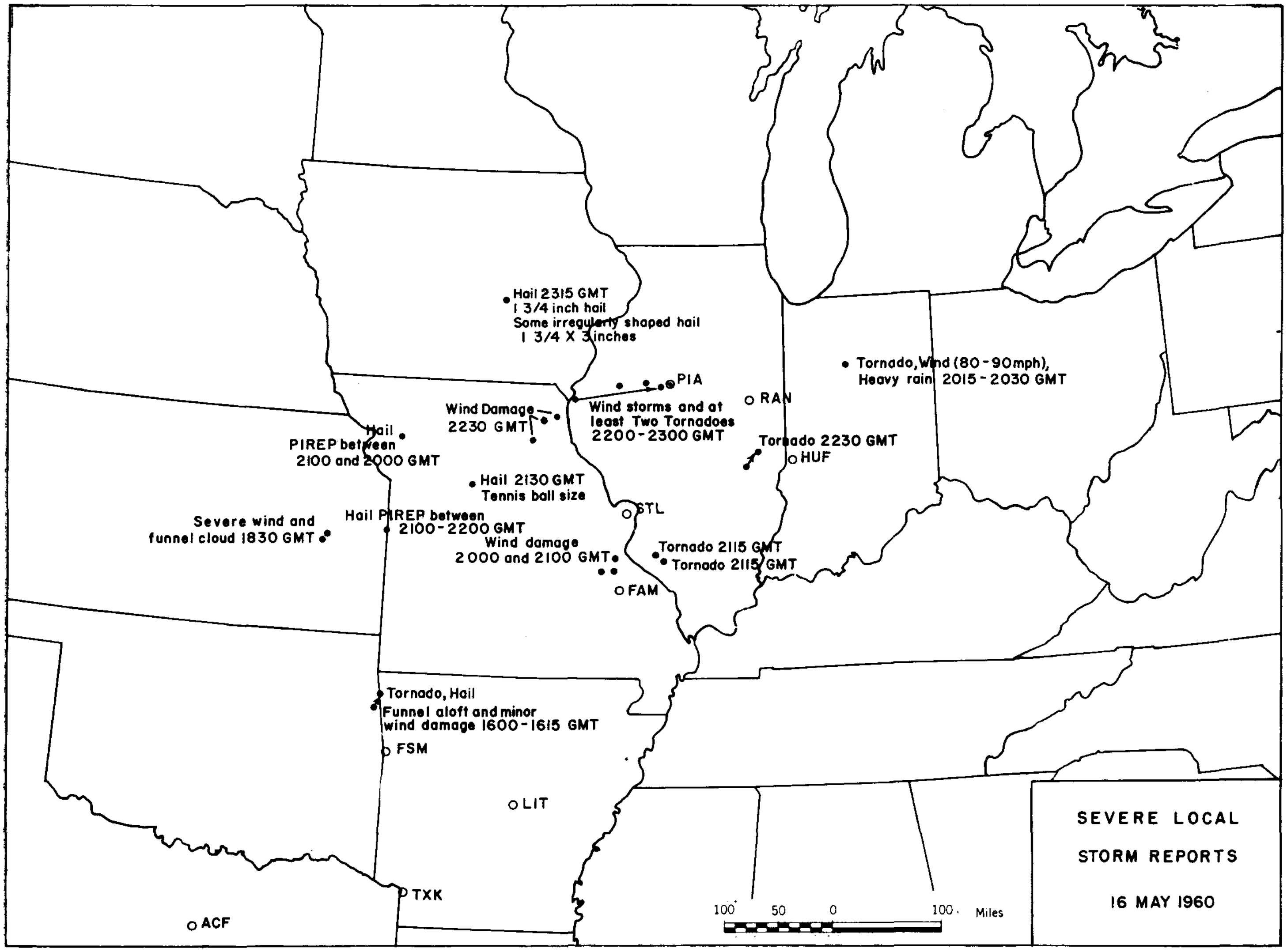

FIGURE 8.—Severe storm reports in the Middle West on May 16, 1960, Greenwich time. Other storms occurred in Kansas and Oklahoma, but these reports are not shown since they had no direct relation to the storms in the Middle West.

curved jet with the wind maximum located at the point of maximum curvature (figs. 12 a and b), and (3) an anticyclonically curved jet with the wind maximum located at the point of maximum curvature (fig. 11b). These models are simplified compared with the many jet structures which may occur, but nonetheless they are useful tools in synoptic meteorology.

Based on the 5,000-ft. and 20,000-ft. streamline charts for 1800 GMT, it was possible using the models to delineate with confidence one area where divergence occurred over convergence. That area (shaded in figs. 11 a and b) east of the jet axes lay over southern Missouri and northern Arkansas or just southeast of cloud mass B where severe weather began breaking out at 2000 GMT.

By 0000 GMT of May 17, 1960, the jet convective mechanism lay over portions of southeastern Iowa, northeastern Missouri, and western Indiana (shaded in figs. 12 a and b). Wind damage and tornadoes occurred in that area with system A during the 2-hour period prior to 0000 GMT. Numerous thunderstorms and some hail within cloud mass A (fig. 3) were forerunners of the tornadoes.

Thus, over the 6-hour interval between 1800 and 0000 GMT, low- and high-level jet maxima and consequently the dynamic convective mechanism were restricted to the immediate vicinity of the two areas of severe weather associated with the cloud masses A and B. Certainly agreement in location between the cloud masses at 2100 GMT and the mechanisms at 1800 and 0000 GMT is not as good as it might be. One must remember that a precise fix of the mechanism is hampered by the wide spacing of the upper air observations, and, in this case, by the lack of time agreement of the upper air observations with the TIROS pictures.

Significantly, the third group of thunderstorms (area C) was neither as severe as the more western systems nor directly under the influence of the jet maxima. During the interval 1800–0000 GMT, system C continually moved eastward away from the dynamic mechanism, lending further support to a decaying thunderstorm situation over Indiana.

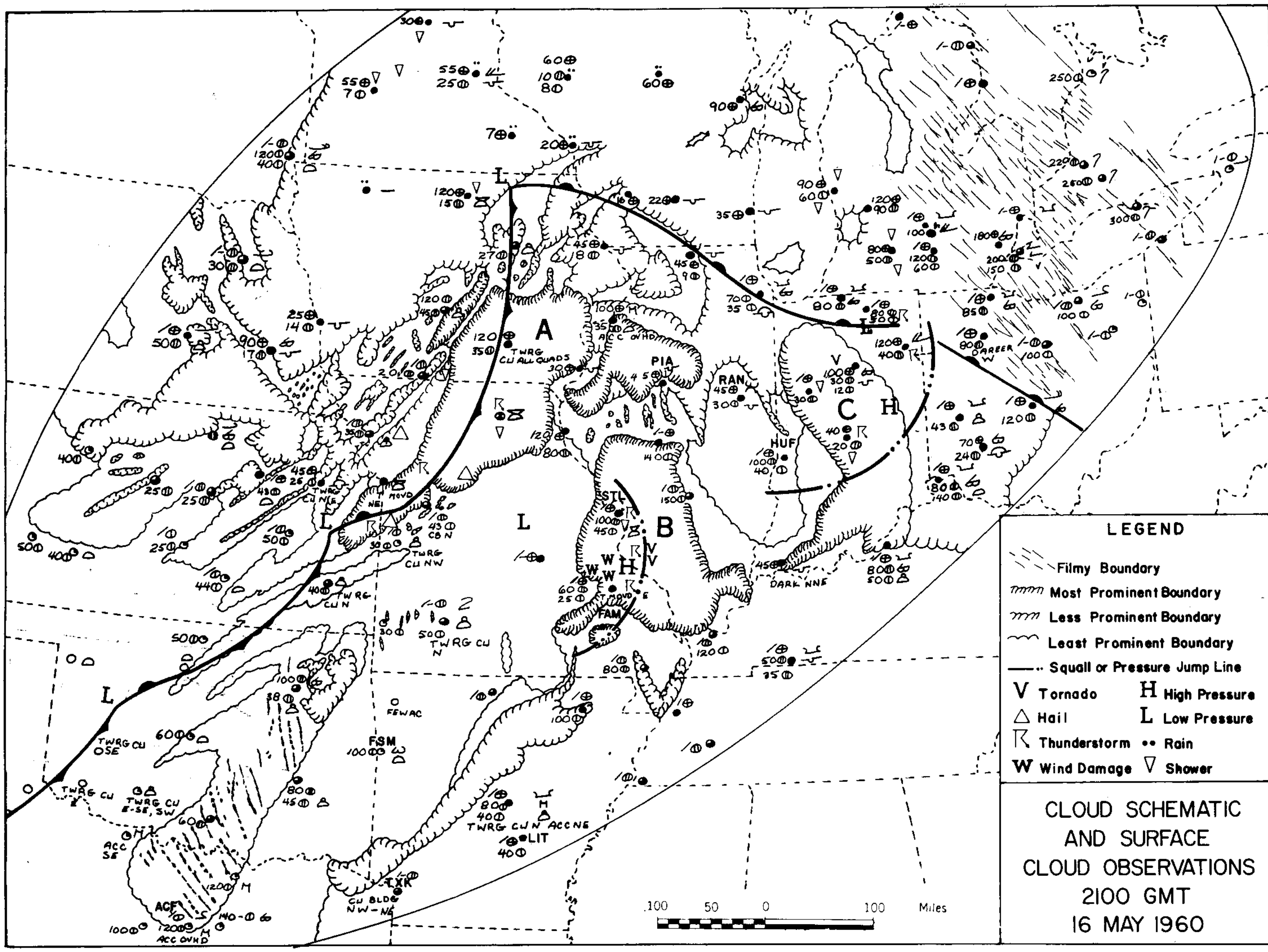

FIGURE 9.—Composite of TIROS cloud schematic and surface observations. Individual station plots give cloud cover, cloud heights, and cloud types. Other features of the diagram are given in the legend.

SURFACE NEPHANALYSIS

The surface-observed sky condition was analyzed according to the following four categories:

1. Overcast low and/or middle clouds; or overcast high clouds with at least broken low and/or middle clouds.
2. Broken low and/or middle clouds but high clouds not overcast if any appear.
3. Broken to overcast high clouds with clear to scattered low and/or middle clouds.
4. Clear skies or scattered low and/or middle clouds.

This form of nephanalysis was adopted since it might better correspond to the apparent cloud cover and brightness seen in the pictures, particularly if the premise is accepted that high clouds are not always readily visible in earth satellite photographs. Experience has shown that unless cirriform clouds are dense, the TIROS cameras do not usually detect them.

In the following few paragraphs, comparisons are made between the TIROS pictures (figs. 1–5) and the surface nephanalysis (fig. 7). The reader may find it beneficial to refer also to the TIROS schematic in figure 6.

In the cold air the overcast area (fig. 7) as described by category 1 above, conforms closely to the standard model of heavy clouds and steady precipitation extending from the warm front counterclockwise around the low pressure center. This overcast region may be discerned in figure 3 as an area of continuous, moderately bright cloud cover.

A second area of overcast skies (category 1) was located in the northern portion of the warm sector. That area contained the cloud masses A, B, and C (figs. 2 and 3).

Areas of broken low and/or middle cloudiness (hatched areas of fig. 7) over Oklahoma and in the central Plains States are reflected in the TIROS pictures as small-scale patches of clouds or as individual cloud elements, some organized into cloud streets.

Those areas on the surface nephanalysis (fig. 7) classified, under category 3, as broken or overcast high cloud (light dotted areas), are seen as either clouds of dull filmy appearance or areas of no cloudiness. In the eastern Lakes area (fig. 5), the clouds were filmy. Over south-central Missouri, figure 3 pictures a very dark area. Yet broken to overcast cirriform cloud cover with few or no lower clouds was reported in both locations (fig. 7). The observations indicated that the high clouds were dense over the eastern Lakes but thin over south-central Missouri.

4. CLOUD INTERPRETATION

In figure 9, the schematic of the five TIROS pictures is shown in composite with the surface cloud observations. From the preceding discussion of the nephanalysis in figure 7 and by inspection of figure 9, one may see that the surface observed cloud cover agrees well with the TIROS observed cloud cover.

There are several positions where the rectified clouds are not consistent with surface observations. These discrepancies indicate a maximum rectification error of about 20 miles. Two examples are Rantoul, Ill. (RAN) and Terre Haute, Ind. (HUF). Both stations reported considerable cloudiness yet lie in a dark portion of the picture which indicates little or no cloudiness. One can see from figure 9 that only a slight geographical readjustment in the rectified cloud schematic would be required to have these stations fall within a cloudy area.

Several interesting comparisons may be drawn from figure 9 with regard to observed clouds and the TIROS observations. For instance, those stations which fell within the bounds of the three very bright cloud masses (A, B, and C) all reported an overcast cover with at least broken clouds in the low and middle layers. These stations indicated a predominance of cumuliform clouds, with cumulonimbus and towering cumulus or showers and thunderstorms being most prevalent.

Observations of middle and high clouds between the numerous heavy cumulus structures suggest that the anvil tops united while spreading out under the influence of the strong winds in the upper levels. It is not surprising then that the cloud masses A, B, and C (figs. 3 and 4) should exhibit continuous cloudiness rather than individual, large cumulus clouds.

Figures 11b and 12b illustrate the strong flow present at 20,000 ft.; the flow pattern at 30,000 ft. (not shown) was very similar. The westerly and southwesterly winds over the clouds A, B, and C (fig. 9) explain the extension of the cloud masses to the east and northeast of the areas of heaviest convection. This effect is particularly noticeable in cloud B where the cloudiness protrudes 50 or more miles ahead of the squall or pressure jump line.

Another interesting feature of the pictures is the moderately bright cloud band oriented northeast-southwest through central Arkansas (fig. 2). Little Rock (LIT) and Texarkana (TXK) recorded towering cumulus to the north, and northwest through northeast, respectively (fig. 9). Both reports give credence to the cloud band position some 20 miles northwest of each station.

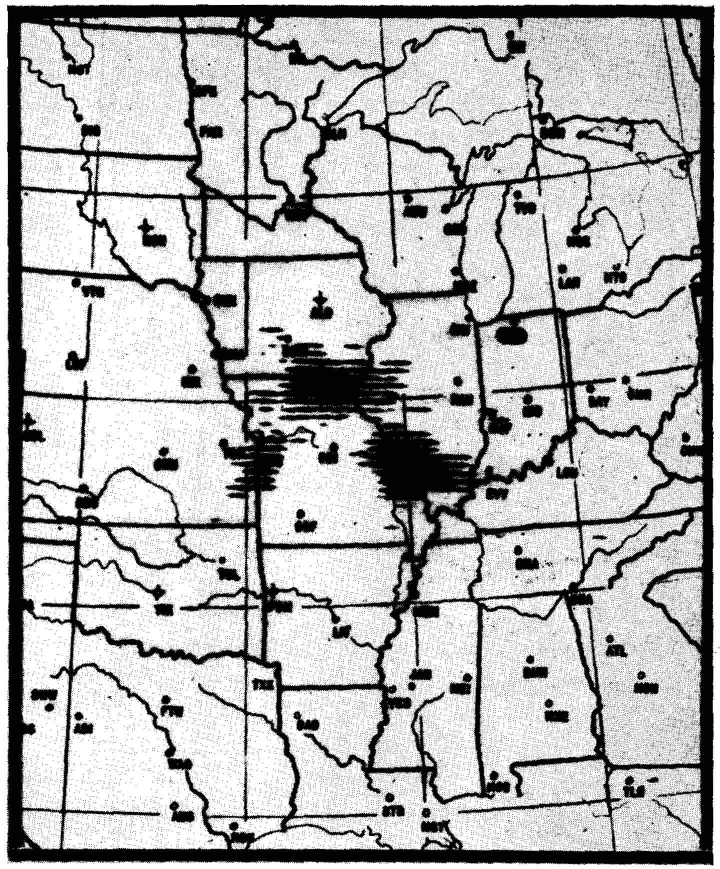

FIGURE 10.—Five-minute, four-station fixes of sferics observations at 2100 GMT, May 16, 1960.

A second apparently overcast area of moderate brightness as seen in the TIROS pictures occurred north of the warm front extending from the western Great Lakes area counterclockwise about the Iowa low pressure center into eastern Nebraska and western Iowa (fig. 9). Station observations within this area all indicated overcast skies while stratocumulus was the most predominantly reported cloud type.

In Kansas, portions of Nebraska, Oklahoma, and north central Texas, the pictures (figs. 1 and 2) convey the impression of broken to occasionally scattered cloud cover comprised largely of convective cells. Many small, individual elements can be seen, some grouped together in patches of irregular size and shape, and some organized into cloud streets. Though the surface observations (fig. 9) do not reveal the details of organization, scattered to broken cover of convective clouds was reported throughout the area—altocumulus castellanus in Texas and cumulus elsewhere.

5. CLOUD STREETS

Cloud streets have been a source of great interest with the advent of rocket and satellite photography.

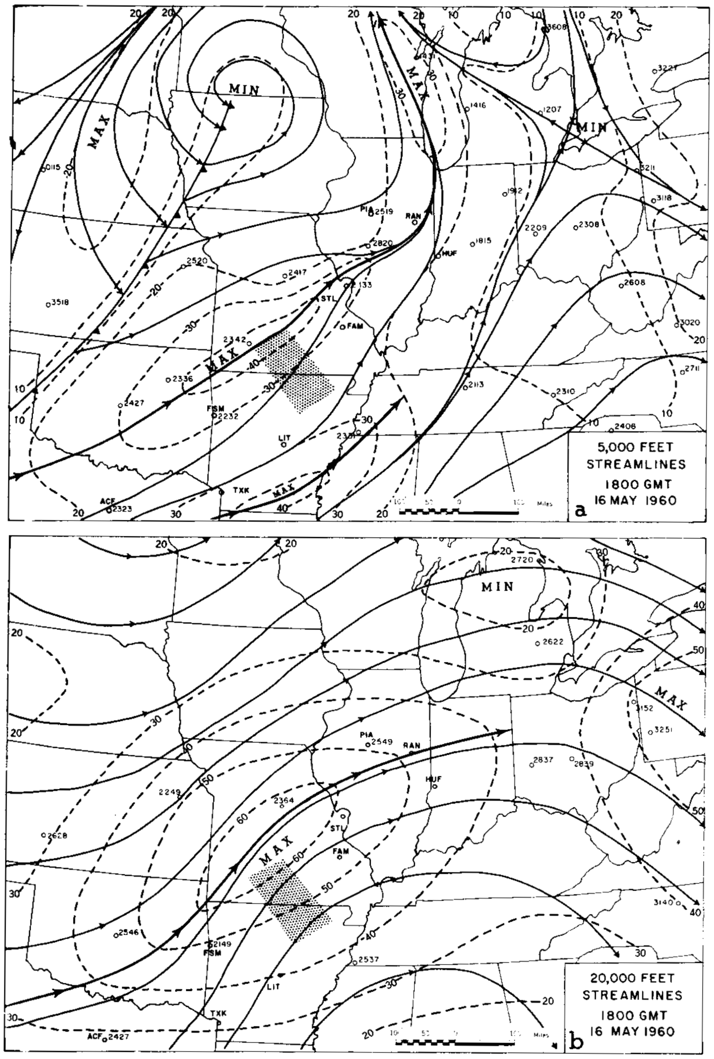

FIGURE 11.—Streamline analyses for May 16, 1800 GMT: (a) 5,000-ft. level; (b) 20,000-ft. level. Shaded area represents the region under the influence of the convective mechanism as determined by the Beebe and Bates [1] models using the 5,000- and 20,000-ft. levels. Jet streams are heavy solid lines; streamlines, light solid lines; and isotachs, dashed lines.

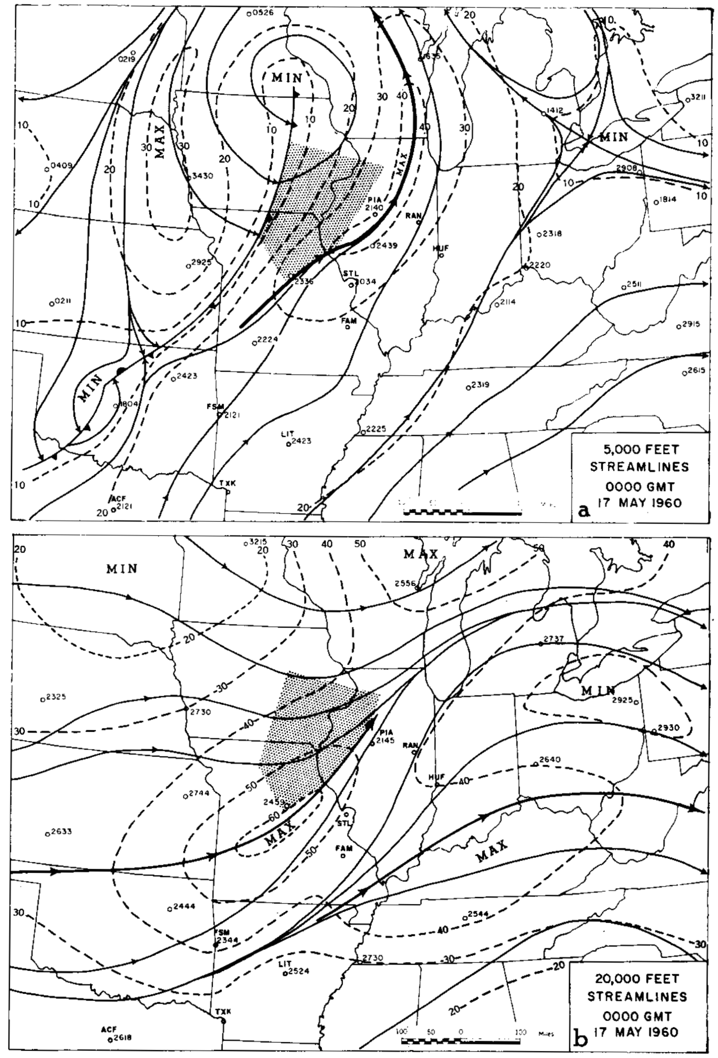

FIGURE 12.—Streamline analyses for May 17, 0000 GMT: (a) 5,000-ft. level; (b) 20,000-ft. level. See legend to figure 11.

The literature has suggested that cloud streets are related to the wind field. Meteorologists, therefore, have been hopeful that observations of cloud streets from satellite vehicles would aid in determining wind directions, particularly in sparse data areas.

Observations from rockets and satellites have shown streets both parallel and perpendicular to the flow or sometimes to the vertical shear. Theories supporting both extremes are propounded in the literature [6, 7]. Kuettner's [7] theory of winds parallel to the streets depends on a "nose" profile of wind speed where speed shear changes sign with height. Haurwitz's [6] theory, on the other hand, supports formation of either billow cloud rolls or cloud streets composed of polygonal cells at an internal boundary surface of density discontinuity, the rolls or streets being normal to the wind shear vector across the boundary.

Surface observations and a sounding in the vicinity of the cloud streets observed by TIROS I (figs. 1 and 2) over Oklahoma on May 16 suggest that these streets conform to the Haurwitz theory. The cloud bases were reported at 4,000 to 6,000 ft. (fig. 12) while the Fort Smith, Ark. (FSM) sounding (fig. 13a), though taken 3 hours earlier, indicated a temperature inversion at approximately the same altitude. The wind shear vector across the inversion surface or internal boundary at Fort Smith was normal to the cloud streets as rectified. Winds immediately below and above the inversion were 190° at 20 kt. and 230° at 37 kt., respectively, which determined a shear vector of 260° at 26 kt. The cloud streets generally formed an angle of 80° to 90° with the shear vector.

Haurwitz indicates that cloud rows can theoretically be at any angle except zero to the wind shear across an internal boundary surface but that normality to the wind

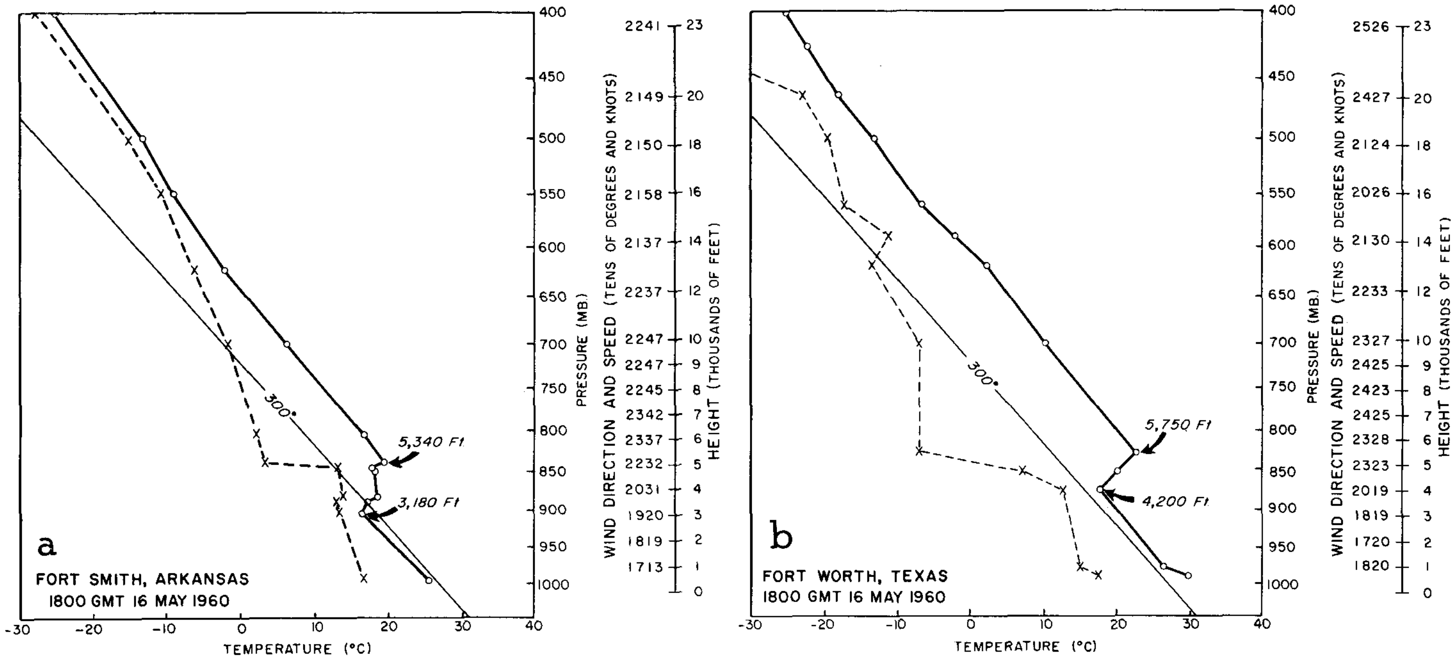

FIGURE 13.—(a) Fort Smith, Ark., sounding. (b) Fort Worth, Tex., sounding. The heavy solid line is the vertical temperature distribution; the broken line, the vertical dew-point distribution; and the light solid line, the 300° K. adiabat.

shear is the most plausible. For the case of perpendicularity, the simplified equation for maximum wavelength (L_∞) for rows or streets of infinite lateral extent is

$$L_\infty=\frac{\pi(\Delta U)^2\overline{T}/g}{[\Delta T^2+(\Delta U)^2\overline{T}(\Gamma-\gamma)/g]^{1/2}} \qquad (1)$$

where g=acceleration of gravity
ΔU=shear speed across the internal boundary
$\overline{T}$=mean absolute temperature of the two layers
ΔT=temperature difference across the boundary
Γ=adiabatic lapse rate or moist adiabatic rate if condensation occurs
γ=lapse rate of the atmosphere which is assumed equal either side of the boundary.

When the waves are of finite lateral extent, as when the streets are composed of cells, the wavelength according to equation (1) is modified as follows:

$$L=\frac{L_\infty}{[1+L_\infty^2/\lambda^2]^{1/2}} \qquad (2)$$

where L equals wavelength of streets of finite lateral extent, and λ equals lateral wavelength or lateral spacing of cells.

Equations (1) and (2) were applied in the May 16 cloud street case using values from the 1800 GMT Fort Smith sounding. Though observed 3 hours earlier, the sounding was nearest the streets in time and space. The theoretical wavelengths or spaces between streets thus determined were 3.3 miles and 1.7 miles (assuming λ to be 1 mile) for waves of infinite and finite lateral extent, respectively. Since the cloud streets in the TIROS pictures appear to be made up of individual cloud cells, then the theoretical wavelength of 1.7 miles would seem to apply. However, the surface observations of cumulus congestus and size of the cloud elements in the pictures indicate the cellular structure is more complicated than the simple cells in streets of finite lateral extent. Then for purposes of this discussion the theoretical spacing of 3.3 miles as an initial condition will be considered. The cloud street spacing in the TIROS photographs is approximately 8 or 9 miles.

Riehl et al. [8] have noted apparent increases in cloud street spacing through enhancement of some streets and suppression of others, particularly when the cumulus became more vertically developed. Conover [3] has observed, through radar, major bands between which were minor bands, more closely spaced. He, too, has noted streets, using time lapse photography, that have disappeared or were suppressed within a pattern of streets. Though not speaking specifically of streets, Byers and Braham [2] observed preferred grouping of cells during the Thunderstorm Project in Florida.

Actually the theoretical treatment of Haurwitz is applicable only to clouds of small vertical development, whereas the streets seen in the pictures are composed of conglomerates of cumulus cells of considerable vertical development. It is reasonable to suppose that the internal boundary waves provided sufficient mechanical vertical motion to release the latent instability for the formation of cumulus congestus. Further, as the cumulus developed some streets were damped while others were accentuated, thus increasing the wavelength. The observed street

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spacing of 8 or 9 miles and a theoretical spacing of 3.3 miles suggest that every third street was enhanced and those in between suppressed.

The presence of cloud streets over extreme north central Texas (fig. 1) is not easily explained. The clouds were based at 12,000 ft., much higher than the inversion at Fort Worth (fig. 13b), and the shear between the 12,000- and 14,000-ft. levels, though small, approximately paralleled the streets. There is then no apparent relationship to the Haurwitz theory at time of the sounding. At cloud level, the wind and streets were perpendicular precluding any obvious relationship to the Kuettner theory.

6. SUMMARY

Evidence has been presented supporting the premise that the isolated brightest mesoscale cloud masses seen in the TIROS pictures of May 16, 1960 were organized systems of numerous thunderstorms capable of producing severe local storms. Further, two of the masses were developing where the strongest convective mechanism was present; that is, the clouds were associated with low- and high-level jet stream maxima and surface fronts or pressure jump lines. The third bright area, though not isolated at picture time, was a manifestation of a decaying group of thunderstorms which had moved eastward for several hours, away from the jet convective mechanism to the west.

Then, with regard to cloud interpretation, it is not surprising that the bright masses were concentrations of cumulus congestus and cumulonimbus clouds observed from the surface. In general, the brightest areas were both overcast and cumuliform in nature, the smaller-scale areas representing cumulus of vertical development and the large-scale area, stratocumulus. Scattered to broken cumulus or cumulus congestus clouds appear in the pictures as darker areas comprised of small cells or irregular bright patches, some organized and some not. Cirriform clouds, overall, gave the poorest reflectivity or none at all, particularly where thin.

The cloud streets appear related to the theory suggesting a perpendicular orientation between wind shear through an inversion and cloud streets which form there.

We have seen that TIROS I has at least on two occasions, May 16 and 19, 1960, clearly demonstrated the capability of television-equipped meteorological satellites to detect severe-weather-producing cloud masses, both prior to storm development and during storm occurrence. In the future, vastly improved television coverage is anticipated in both time and space so that satellites are likely to be effective tools for both detection and tracking of mesoscale severe weather systems.

REFERENCES

1. R. G. Beebe and F. C. Bates, "A Mechanism for Assisting in the Release of Convective Instability," *Monthly Weather Review*, vol. 83, No. 1, Jan. 1955, pp. 1–9.
2. H. R. Byers and R. R. Braham, Jr., "Thunderstorm Structure and Circulation," *Journal of Meteorology*, vol. 5, No. 3, June 1948, pp. 71–86.
3. J. H. Conover, "Cloud Patterns and Related Air Motions Derived by Photography," *Final Report* on Contract No. AF 19(604)–1589, Harvard University, Blue Hill Meteorological Observatory, 1959, 268 pp. (see pp. 246–252).
4. Department of the Air Force, Air Weather Service, "Uses of Sferics in Analysis and Forecasting," *Air Weather Service Manual* 105–38, 1953, 32 pp.
5. T. Fujita, H. Newstein, and M. Tepper, "Mesoanalysis: An Important Scale in the Analysis of Weather Data," U.S. Weather Bureau, *Research Paper* No. 39, 1956, 83 pp.
6. B. Haurwitz, "Internal Waves in the Atmosphere and Convective Patterns," *Annals of the New York Academy of Sciences*, vol. 48, 1949, pp. 722–748.
7. J. Kuettner, "The Banded Structure of the Atmosphere," *Tellus*, vol. 11, No. 3, Aug. 1959, pp. 267–294.
8. H. Riehl, W. S. Gray, J. S. Malkus, and C. Ronne, "Cloud Structure and Distributions over the Tropical Pacific, Part I," Woods Hole Oceanographic Institution, *Technical Report* No. 5, 1959, 61 pp. (Unpublished manuscript).
9. C. E. Palmer, C. W. Wise, L. J. Stempson, and G. H. Duncan, "The Practical Aspect of Tropical Meteorology," *Air Force Surveys in Geophysics*, No. 76, U.S. Air Force, Geophysics Research Directorate, 1955, 195 pp., (see pp. 65–100).
10. Staff Members, Meteorological Satellite Laboratory, U.S. Weather Bureau, "Some Meteorological Results from TIROS I," 1961, to be published in Report on TIROS I by the National Aeronautics and Space Administration, (in press).
11. L. F. Whitney and S. Fritz, "A Tornado-Producing Cloud Pattern Seen from TIROS I," *Bulletin of the American Meteorological Society*, vol. 42, No. 9, Sept. 1961, pp. 603–614.